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ATTORNEYS AT LAW

Docket No.: 240625US6

COMMISSIONER FOR PATENTS
ALEXANDRIA, VIRGINIA 22313

RE: Application Serial No.: 10/621,362
Applicants: Jasper Jan WICKERHOFF, et al.
Filing Date: July 18, 2003
For: AN AEROPLANE PROVIDED WITH NOISE-REDUCING MEANS, AS WELL AS A LANDING GEAR AND BLOWING MEANS
Group Art Unit: 3643
Examiner: Swiatek, Robert P.

SIR:

Attached hereto for filing are the following papers:

Appeal Brief
Mech 386 - Topic 6

Our credit card payment form in the amount of **$500.00** is attached covering any required fees. In the event any variance exists between the amount enclosed and the Patent Office charges for filing the above-noted documents, including any fees required under 37 C.F.R 1.136 for any necessary Extension of Time to make the filing of the attached documents timely, please charge or credit the difference to our Deposit Account No. 15-0030. Further, if these papers are not considered timely filed, then a petition is hereby made under 37 C.F.R. 1.136 for the necessary extension of time. A duplicate copy of this sheet is enclosed.

Respectfully submitted,

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IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF:

Jasper Jan Wickerhoff, et al. EXAMINER: Swiatek, Robert P.

SERIAL NO. 10/621,362

FILED: July 18, 2003 GROUP ART UNIT: 3643

FOR: AN AEROPLANE PROVIDED WITH NOISE-REDUCING MEANS, AS WELL AS A LANDING GEAR AND BLOWING MEANS

APPEAL BRIEF

COMMISSIONER FOR PATENTS
ALEXANDRIA, VIRGINIA 22313

SIR:

This is an appeal from the decision of the Examiner dated October 8, 2004, which finally rejected Claims 1-3, 7, 10-12 and 14 in the above-identified patent application. A Notice of Appeal was timely filed with a three month extension of time on April 6, 2005.

I. REAL PARTY-IN-INTEREST

The real part-in-interest is SP Aerospace and Vehicle Systems B.V.

II. RELATED APPEALS AND INTERFERENCES

Appellants, Appellants' legal representative, and the assignees are aware of no appeals which will directly affect or be directly affected by or have a bearing on the Board's decision in this appeal.

III. STATUS OF CLAIMS

Claims 1-3, 7, 10-12 and 14 have been finally rejected and form the basis for this appeal. Claims 4-6, 8, and 9 have been objected to as dependent on a rejected based claim, but have been indicated to be otherwise allowable if rewritten in independent form including all the limitations of the base claim and any intervening claims. Claim 13 has been canceled. Appendix VIII includes a clean copy of appealed Claims 1-3, 7, 10-12 and 14.

IV. STATUS OF AMENDMENTS

No amendments after final rejection have been filed.

V. SUMMARY OF CLAIMED SUBJECT MATTER

Independent Claim 1 is directed to an aeroplane provided with a noise-reducing unit configured to reduce a noise level produced during a flight, in particular during a landing stage of the aeroplane, due to landing gear of the aeroplane. The noise reducing unit includes a blowing unit having a blowing element including at least one blowing nozzle for creating an air screen at a front side of a portion of or all of the landing gear. An exemplary embodiment is shown in Figure 1 and described in the specification from page 8, line 24 to page 9, line 9. In this exemplary embodiment, the blowing unit includes blowing element 4 with blowing nozzle 5 configured to create air screen 7 in front of landing gear 1.

Independent Claim 12 is directed to a blowing unit including at least one blowing nozzle for creating an air screen at a front side of a portion of the landing gear. An exemplary embodiment is shown in Figure 1 and described in the specification from page 8, line 24 to page 9, line 9. In this exemplary embodiment, the blowing unit 4 includes blowing

nozzle 5 configured to create air screen 7 in front of landing gear 1.

Independent Claim 14 is directed to a deflection element configured to create an air screen at a front side of a portion of the landing gear. An exemplary embodiment is shown in Figures 12a and 12b and described in the specification from page 14, line 23 to page 15, line 2. In this exemplary embodiment, the deflection element is made up of two curved deflection sections 90, 91 that are configured to create air screen 96 in front of the landing gear.

VI. GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL

The grounds of rejection to be reviewed on appeal are:

(a) whether Claims 1, 2, 10/1, 10/2, 11/1, 11/2, 12 and 14 are anticipated under 35 U.S.C. §102(b) by Mayer, Jr.; and

(b) whether Claims 1-3, 7, 10-12, and 14 are anticipated under 35 U.S.C. §102(b) by Passler.

VII. ARGUMENTS

A. Introduction

Claim 14 recites a noise-reducing unit comprising:

> a deflection element configured to create an air screen at a front side of a portion of the landing gear, said air screen configured to deflect air flow away from said portion of said landing gear to reduce said noise.

Claim 12 recites a blowing unit comprising:

> a blowing element including at least one blowing nozzle configured to create an air screen at a front side of a portion of the landing gear, said air screen configured to deflect air flow away from said portion of said landing gear to reduce said noise.

Claim 1 recites an aeroplane provided with a noise-reducing unit comprising:

> a blowing unit having a blowing element including at least one blowing nozzle for creating an air screen at a front side of a portion of or all of the landing gear, said air screen configured to deflect air flow away from said portion of said landing gear to reduce said noise level.

B. Claims 1, 2, 10/1, 10/2, 11/1, 11/2, 12 and 14 are not anticipated by Mayer, Jr.

The Final Office Action concludes that Claims 1, 2, 10/1, 10/2, 11/1, 11/2, 12 and 14 are anticipated under 35 U.S.C. §102(b) by Mayer, Jr. based on the description of air slots 22 in Mayer, Jr.:

> The aircraft of Mayer Jr. includes a series of control slots 22 situated in the upper portion of its nose, as well as along upper surfaces of the wings and horizontal stabilizer. A separate blower - deemed to constitute a compressor - or the aircraft's engine directs air through the slots to improve control and handling of the aircraft. Although the nose slots 22 of Mayer Jr. extend only partially around the nose, the lowermost ones of slots 22 direct high velocity air downwardly and tangent to the nose. This downwardly-directed air from lowermost slots 22 of Mayer Jr. would serve to deflect at least a minimal amount of the oncoming airflow from the landing gear of the craft by entraining it and conducting it away from the craft.[1]

1. Factual misunderstanding of teachings of Mayer, Jr.

Meyer, Jr. describes a boundary layer control means including slots 17, 20, and 22 configured to discharge air along the surface of a wing or fuselage of an airplane to increase the speed of the air in the boundary layer of the wing or fuselage. According to Mayer, Jr., the increased air speed lowers the air pressure in the boundary layer.[2] Lower air pressure in the boundary layer leads to an aerodynamic force, which can be used to change the attitude of the aircraft.

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[1] Outstanding Office Action, page 2, lines 7-15.

[2] See Meyer, column 1, lines 4-16, column 2, lines 42-48, column 5, lines 6-20, and Figures 1 and 2.

However, the described aircraft control system does not teach the elements of the claimed invention, as alleged in the Final Office Action. First, it is respectfully submitted that the location of the landing gear in Mayer, Jr. has not been shown or described. Accordingly, the assertion in the Final Office Action that "This downwardly-directed air from lowermost slots 22 of Mayer Jr. would serve to deflect at least a minimal amount of the oncoming airflow from the landing gear of the craft by entraining it and conducting it away from the craft" is pure speculation, and contrary to the designs of aircraft known in the art. Typical landing gear would be located along the centerline of the fuselage well separated from the lowermost slot 22 shown in Figure 1, and/or under the wings. Applicant is unaware of an aircraft where the landing gear is located at the boundary between the wing and the fuselage. For example, the landing gear could be mounted under the wings as disclosed by De Seversky, which was cited as of interest to landing gear arrangements in the Action mailed April 21, 2004. Thus, it is respectfully submitted that the lowermost slot 22 shown in Figure 1 of Mayer, Jr. is not located such that any air flowing from it would inherently serve to screen the landing gear.

Further, one skilled in the art would recognize that the lowermost slot 22 would not affect the air flow at a level even with the landing gear, assuming *arguendo* that the landing gear was located by pure chance to be below the slot 22. It is respectfully submitted that the materials included in the Evidence Appendix reflect the knowledge of those skilled in the art regarding boundary layers. The materials state that a boundary layer is a thin region located near a surface in a flow.[3] The materials also include examples of boundary layer thicknesses for a Boeing 747, one of the largest airplanes available. Using the exemplary values,

[3] See MECH 386 - TOPIC 6, page 1, lines 4 and 5.

including a mean chord length of 8.6 m for a Boeing 747, the following boundary layer thicknesses were computed. For laminar flow, the boundary layer is only 7.5 mm, and, for turbulent flow, the boundary layer is only 116 mm (less than 5 inches!).[4] It is respectfully submitted that for smaller planes, the mean chord length will be smaller, leading to even smaller boundary layers. Thus, it is respectfully submitted that one skilled in the art would realize that a boundary layer control apparatus as disclosed by Mayer, Jr. would not affect the landing gear in any way, as the landing gear extends far beyond the thickness of the boundary layer around the fuselage. Moreover, the nose slots 22 are expressly taught to be "in the upper portion of the forward area to the fuselage" at column 5, lines 28-30 of Mayer, Jr. Clearly, they are not taught to even be present under the fuselage where any landing gear could be mounted.

2. Legal Inadequacy of the Rejection

The assertion in the Office Action essentially alleged that the invention recited in Claims 1, 12, and 14 was inherently disclosed by Mayer, Jr. However, it is respectfully submitted that a factual showing of inherency has not been made, nor have any technical reasons been presented to establish such inherency.

"To establish inherency, the extrinsic evidence 'must make clear that the missing descriptive matter is necessarily present in the thing described in the reference, and that it would be so recognized by persons of ordinary skill. Inherency, however, may not be established by probabilities or possibilities. The mere fact that a certain thing may result from a given set of circumstances is not sufficient.'" *In re Robertson*, 169 F.3d 743, 745, 49

[4] See MECH 386 - TOPIC 6, pages 4 and 5.

USPQ2d 1949, 1950-51 (Fed. Cir. 1999) (emphasis added, citations omitted). See also MPEP §2112 IV citing *Ex parte Levy*, 17 USPQ2d 1461, 1464 (Bd. Pat. App. & Int. 1990) requiring that any theory of inherency be supported at least by technical reasoning that is completely absent here.

It is respectfully submitted that none of the requirements stated in the above controlling case law have been met. First, no extrinsic evidence has been cited or provided supporting the assertions made in the Final Office Action. Further, as stated above, it is respectfully submitted that no technical reasoning has been provided in support of the assertion and that one skilled in the art would realize that the apparatus described in Mayer, Jr. fails to inherently teach the invention recited in Claim 1 because any reasonable placement of the landing gear relative to the Mayer, Jr. aircraft would be well away from the slots and boundary layer they establish, so that there would be no resulting air screen to shield the landing gear. Accordingly, it is respectfully submitted that Mayer, Jr. does not teach or suggest, explicitly or inherently, the subject matter of Claims 1 and 12 as to nozzle created air screens.

With regard to Claim 14, Mayer, Jr. also does not teach or suggest "a deflection element configured to create an air screen at a front side of a portion of the landing gear, said air screen configured to deflect air flow away from said portion of said landing gear to reduce said noise."

Since Mayer, Jr. does not teach, explicitly or inherently, each and every element of Claims 1, 12, and 14, Claims 1, 12, and 14 are clearly not anticipated by Mayer, Jr. Accordingly, reversal of the rejection of Claims 1, 2, 10/1, 10/2, 11/1, 11/2, 12 and 14 is believed to be in order.

C. Claims 1-3, 7, 10-12, and 14 are not anticipated by Passler

The Final Office Action concludes that Claims 1-3, 7, 10-12, and 14 are anticipated under 35 U.S.C. §102(b) by Passler based only on the diagrammatic showing of blower unit 1 in Passler:

> The Passler reference discloses a blower unit 1 with a series of horizontally-oriented nozzles through which air is expelled outwardly and downwardly. The unit is mounted to the underside of an aircraft and in advance in of the tires of an aircraft's landing gear (see Figures 1, 2 of Passler) such that some of the expelled air inherently would deflect - in the nature of an air screen - ambient air away from a portion of the tires, thereby reducing the noise level. For example, air exiting the blowing unit 1 of Passler to the right and left would entrain some oncoming air, diverting it accordingly to both sides. Whether one skilled in the art would recognize the existence of this process would seem to be secondary to the fact that it does occur.[5]

1. Factual misunderstanding of teachings of Passler

Passler describes an apparatus for blowing water off the runway in front of the tires of a plane that is landing, to prevent the tires from hydroplaning on puddles on the runway.[6] Accordingly, the artisan would have provided blower unit 1 so that it blows air roughly horizontally at a level near the bottom of the tires of the aircraft to ensure that the tires do not go through any puddles to avoid hydroplaning.

The purpose of Passler, to blow water off the runway in advance of the landing gear wheels, at least suggests that the air streams produced must be forward of the landing gear or they would not be able to clear water away before the tires reached the cleared area. The distance would be dependent on many factors, but not on any desire to provide the claimed

[5] Outstanding Office Action, page 2, lines 17 to page 3, line 4.
[6] See Passler, Figures 1-4.

air screen to deflect air from the landing gear as recited by Claim 1, for example.

Furthermore, it is clearly not reasonable to simply assume that the blower unit 1 of Passler would inherently form an air screen in front of a portion of the landing gear to reduce noise caused by the landing gear, as is done at the top of page 3 of the outstanding Office Action as to the assumed entraining of oncoming air to divert it sideways. The purpose taught by Passler is not to position blower unit 1 so that it can provide an air stream to entrain ambient air and direct air away from the landing gear. Instead, it is respectfully submitted that the purpose for the blower unit 1 is to blow water from the runway before the tires reach it. Accordingly, the blower 1 would be located just above the ground and in front of the tires. Moreover, it appears that the tube 2 and support 8 shown by Passler would be more likely to significantly increase the noise level of the plane as it lands, not decrease it.

It is respectfully noted the characterization of Passler included herein is based solely on inspection of the drawings of Passler. The translation of a foreign document, required by MPEP §706.02 II to be provided before making a final rejection, has still not been provided to Applicants.

2. Legal Inadequacy of the Rejection

Again, it is respectfully submitted that the legal requirements for a showing of inherency have not been met. First, no extrinsic evidence has been cited or provided supporting the assertions made in the Final Office Action. In fact, as stated above, a translation of the reference itself has not even been provided to support the allegations in the Final Office Action.

Second, it is respectfully submitted that no reasonable technical reasoning in support

of the assumption made in the outstanding Office Action has been presented as to the blowing nozzle created air screen of independent Claims 1 and 12, much less the deflection element created air screen of independent Claim 14.

Accordingly, Claims 1, 12, and 14 (and Claims 2, 3, 7, 10, and 11 dependent therefrom) are believed to define over Passler for at least the reasons discussed above.

Conclusion

It is respectfully requested that the outstanding rejections be REVERSED.

Respectfully submitted,

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VIII. CLAIMS APPENDIX

1. An aeroplane provided with a noise-reducing unit configured to reduce a noise level produced during a flight, in particular during a landing stage of the aeroplane, due to landing gear of the aeroplane, comprising:

a blowing unit having a blowing element including at least one blowing nozzle for creating an air screen at a front side of a portion of or all of the landing gear, said air screen configured to deflect air flow away from said portion of said landing gear to reduce said noise level.

2. An aeroplane according to claim 1, wherein said at least one blowing nozzle is elongated in shape.

3. An aeroplane according to claim 2, wherein said at least one blowing nozzle is horizontally oriented, facing in a downward direction.

7. An aeroplane according to claim 3, wherein the blowing nozzle is attached to an underside of a fuselage of the aeroplane.

10. An aeroplane according to one of claims 1, 2, or 3, wherein the blowing unit further comprises a compressor that is connected to the blowing element.

11. An aeroplane according to one of claims 1, 2, or 3, further comprising:

a deflection element configured to deflect air in a path of the landing gear.

12. A blowing unit configured to cooperate with an aeroplane landing gear to reduce noise caused by the landing gear, said blowing unit comprising:

a blowing element including at least one blowing nozzle configured to create an air screen at a front side of a portion of the landing gear, said air screen configured to deflect air flow away from said portion of said landing gear to reduce said noise.

14. A noise-reducing unit configured to reduce noise created by an aeroplane landing gear, said noise-reducing unit comprising:

a deflection element configured to create an air screen at a front side of a portion of the landing gear, said air screen configured to deflect air flow away from said portion of said landing gear to reduce said noise.

IX. EVIDENCE APPENDIX

Enclosed herewith is a copy of educational materials (MECH 386 - TOPIC 6) available on the website of the University of British Columbia (http://batman.mech.ubc.ca/~green/MECH386/Topic%206.htm). This evidence was originally submitted with the Request for Reconsideration filed January 10, 2005.

MECH 386 – TOPIC 6

Boundary Layers, Separation, and Drag

Refresher Course on Boundary Layers

- As you have seen in MECH 380 or equivalent courses, boundary layers are *thin* regions located near a surface in a flow
- Let's denote the local coordinate parallel to the surface by x (with associated velocity component u) and the coordinate perpendicular to the surface by y (with associated velocity component v)
- We may do this even if we have a curved surface
- If we denote the local freestream velocity by U_∞ then we typically define the boundary layer thickness as the height (in the y direction) δ above the surface at which u=0.95 U_∞
- As you will recall from our discussion of the Law of the Wall, even in a turbulent flow, the laminar sublayer is a region of the flow in which velocity gradients ($\partial u / \partial y$) are exceptionally high, and therefore laminar viscous effects are dominant
- In laminar boundary layers too ($\partial u / \partial y$) is very large. Both laminar and turbulent boundary layers are thus regions with large velocity gradients

Q: Sketch below the velocity profile through typical laminar and turbulent boundary layers.

A:

Q: For a flat plate with no pressure gradient, do you recall how the laminar boundary layer thickness varies with distance along the plate?
A:

Q: For a flat plate with no pressure gradient, do you recall how the turbulent boundary layer thickness varies with distance along the plate?
A:

- In addition to δ, two other boundary layer thicknesses are useful:

$$\delta^* = \frac{1}{U_\infty}\int_0^\infty [U_\infty - u(y)]dy$$

where δ* is the ***displacement thickness***, and

$$\theta = \frac{1}{U_\infty^2}\int_0^\infty u(y)[U_\infty - u(y)]dy$$

where θ is the ***momentum thickness***

- The displacement thickness is the thickness of the fluid layer moving at U_∞ necessary to make up for the mass flow deficit in the boundary layer
- The momentum thickness is the thickness of the fluid layer moving at U_∞ necessary to make up for the momentum flux deficit in the boundary layer
- For a laminar flat plate boundary layer with no pressure gradient, $\delta^* \approx \delta/3$ and $\theta \approx 2\,\delta/15$
- The ***shape factor*** of a boundary layer is given by $H=\delta^*/\theta$
- For a Blasius Boundary Layer, H =2.59

Calculation of H for a Turbulent Boundary Layer

- In a flat plate turbulent boundary layer without an imposed pressure

gradient, the approximate velocity distribution through the boundary layer is given by:

$$\frac{u}{U_\infty}=\left(\frac{y}{\delta}\right)^{1/7}$$

Q: Can you evaluate H for a turbulent boundary layer?
A:

$$\theta=\int_0^\delta\left({y\over\delta}\right)^{1/7}\left[{1-\left({y\over\delta}\right)^{1/7}}\right]dy=(7/72)\delta \tag{8}$$

$${\rm Also,}\, \delta^*=\int_0^\delta\left[1-\left({y\over\delta}\right)^{1/7}\right]dy=(1/8)\delta\qquad H={\delta^*\over\theta}=1.3 \tag{9}$$

- As we have just seen, H is smaller for a turbulent boundary layer than for a laminar one
- The value of H is an indication of how prone a boundary layer is to separation
- For laminar boundary layers, if H=3.5 separation is imminent
- For turbulent boundary layers, if H=2.4 separation is imminent
- Smaller H is good in terms of avoiding separation because it implies higher transverse momentum exchange in the boundary layer
- In other words, if H is small, higher momentum fluid from further away from the wall is brought closer to the wall. This fluid has more kinetic energy and is therefore more capable of "coping with" adverse pressure gradients
- H is used in various sophisticated methods (e.g. Head's method) for computing laminar and turbulent boundary layer growth. Those methods

are beyond the scope of this course.

Transition

- All boundary layers start life as laminar boundary layers, and at some distance along the surface (this location may be very near the start of the surface), the flow ***transitions*** to turbulent
- The location of transition is a function of many variables, including the local freestream turbulence level, the pressure gradient along the surface, the surface roughness, and the local Reynolds number, Re_x
- For a rough flat plate with some turbulence in the freestream, the transition Reynolds number is about Re_x=500,000
- If the plate is very smooth and the freestream has a low turbulence level, one may delay transition to Re_x=3,000,000
- With the strongly favourable pressure gradient that occurs in a converging nozzle, for example, a previously turbulent flow may transition back to laminar, a process called ***relaminarization***

Simple Example

A Boeing 747 wing has a mean chord of 8.6 m, a wing span of 60 m, and flies at 280 m/s at an elevation of 15 000m.

1. Estimate the boundary layer thickness at the end of the wing if the flow were laminar everywhere.
2. Re-estimate this thickness if the flow were turbulent everywhere.
3. What is the approximate transition location?

SOLUTION

$$\mathrm{Re}_L = \left(\frac{280 \times 8.6}{7.3 \times 10^{-5}}\right) = 3.3 \times 10^7$$

If the flow were laminar everywhere the boundary layer thickness would be

$$\delta = \frac{5.0 \times L}{\sqrt{\mathrm{Re}_L}} = \frac{5.0 \times 8.6}{\sqrt{3.3 \times 10^7}} = 7.5mm$$

at the trailing edge of the wing!!

If the flow were turbulent (obviously the case for such a large Re_L), then

$$\delta = \frac{0.16 \times L}{(\mathrm{Re}_L)^{1/7}} = \frac{0.16 \times 8.6}{(3.3 \times 10^7)^{1/7}} = 116mm$$

which is much larger than the laminar result.

If we assume transition occurs for $\mathrm{Re}_x = 5 \times 10^5$ then

$$x_{transition} = \frac{5 \times 10^5 \times 7.30 \times 10^{-5}}{280} = 0.13m$$

Transition occurs 0.13 m from the wing leading edge. Most of the wing sees turbulent flow. A huge effort is underway at aircraft companies to move back the location of transition, through (proprietary) wing shape modification

Separation

Q: What do we mean when we say that flow separates from a surface?
A:

- In two-dimensional flow, the wall shear stress drops to zero at the location of separation

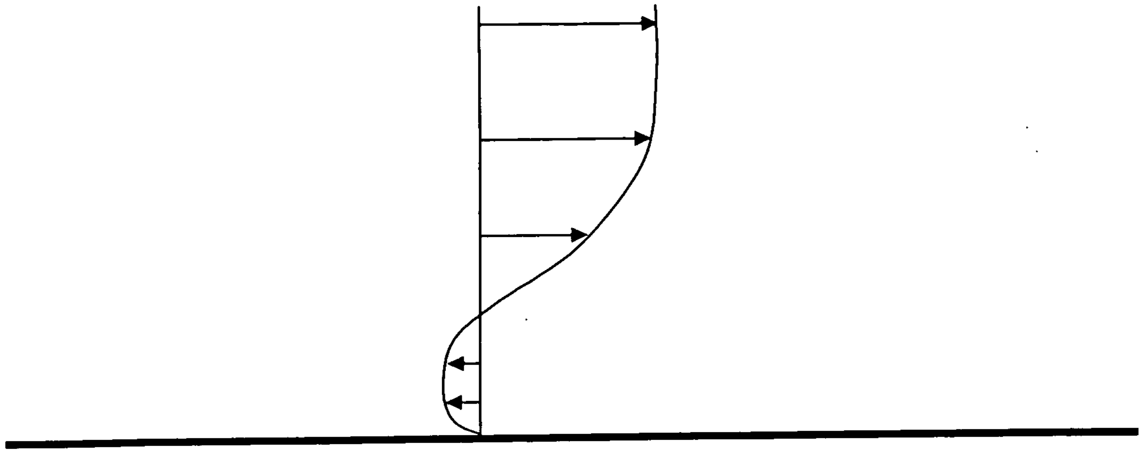
Q: Can you explain why?
A:

- At a wall in either a laminar or turbulent boundary layer, one may show easily that:

$$\left.\frac{\partial^2 u}{\partial y^2}\right|_{wall} = \frac{1}{\mu}\frac{dp}{dx}$$

Q: If one has an unfavourable or adverse pressure gradient, what is the sign of *dp/dx*?
A:
Q: In view of the above, can you sketch *u*(*y*) very near the wall?
A:

- If dp/dx is sufficiently positive (sufficiently adverse pressure gradient), then the flow separates from the wall:



- As alluded to above, one way to predict whether separation will occur is to compute the value of H along a surface.
- Thwaites' method is an example of a separation calculation procedure involving H that works quite well, but only for laminar flow
- Turbulent separation calculation procedures also exist, but are very complex and are not as reliable
- Separation is, however, very easy to see experimentally by means of dye injection or tufts:

Figure 32 of van Dyke

Figure 33 of van Dyke

Figure 38 of van Dyke

Figure 47 of van Dyke

- Separation in highly three-dimensional flow is more difficult to describe precisely. It is **not** true that the wall shear stress drops to zero in a 3D separated flow:

Figure 74 of van Dyke

Sources of Drag

- The drag in any flow can be divided into two components: ***skin friction drag*** and ***pressure drag***

Skin Friction Drag

- We understand skin friction drag intuitively. Consider two cases, a pipe flow and the flow over an airfoil:

- For both cases (and in fact, in all cases), the skin friction drag may be expressed as the component of the shear stress in the freestream direction, on the object's surface, integrated over the surface area
- The local shear stress is a function of three variables: the flow Reynolds number, the local pressure gradient, and the surface roughness

Figure 7.6 of White

- For a laminar (Blasius) boundary layer the drag coefficient is:

$$c_D = \frac{1.328}{\mathrm{Re}_L^{1/2}}$$

- Note that, just as for the Moody diagram (pipe flow), c_D is independent of plate roughness

Q: Why is this so?
A:

- Prandtl and Schlichting have developed an expression for smooth flat plate c_D in turbulent flow, valid to Re=10^9:

$$c_D = \left(\frac{0.455}{\log \mathrm{Re}_L}\right)^{2.58} - \frac{1700}{\mathrm{Re}_L}$$

Q: How do you think the skin friction drag with a favourable pressure gradient compares with that for a flat plate (for which dp/dx=0)?
A:

- Unlike for laminar flow, roughness plays a large role in turbulent flat plate drag. When Re is sufficiently high, c_D is given by:

$$c_D = \left(1.89 + 1.62 \log \frac{L}{\varepsilon}\right)^{-2.5}$$

- Don't forget that the above two expressions are only valid for flat plates parallel to a stream (zero pressure gradient)

Q: Compare the laminar and turbulent drag on a smooth flat plate at Re=500,000

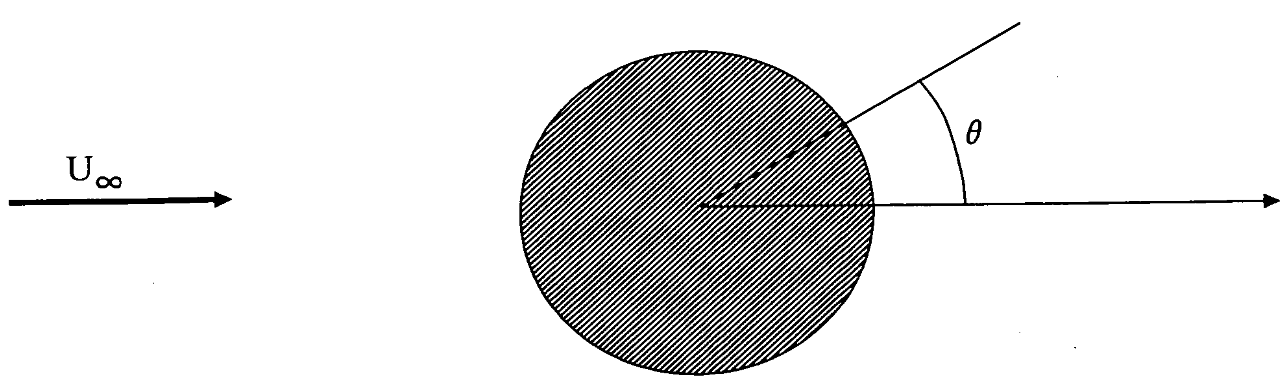
A:

- So, one way to minimize drag on a surface is to ensure that the flow remains laminar as long as possible
- Prolonged laminar flow may be attained in several ways:
  1. Reduce freestream turbulence, e.g. as produced by objects upstream
  2. Ensure a favourable pressure gradient exists (body shaping)
  3. Smooth surfaces to avoid stimulating transition

Pressure Drag

- Pressure drag is also fairly easy to understand. It is the integrated component of the pressure force, in the direction of the flow

Q: Consider a cylinder in a flow. If the pressure distribution is symmetric fore and aft, what is the pressure drag on the cylinder?



A:

Q: If the pressure at the front of the cylinder is given by: $p(\theta) = p_\infty + \frac{1}{2}\rho U_\infty^2\left(1 - 4\sin^2\theta\right)$, and for $|\theta| < 90°$ it is $0.5p_\infty$, find the pressure drag on the cylinder.

A:

- The low pressure on the back side of the cylinder is referred to as the ***base pressure***
- It is this low pressure that is the primary source of pressure drag
- For bluff bodies, where the region of flow separation is large, the pressure drag can be an order of magnitude or more larger than the skin friction drag
- For this reason, reducing the drag on a bluff body is all about reducing the pressure drag
- We can theoretically reduce the pressure drag in two ways – by increasing the base pressure and by reducing the size of the region exposed to the low base pressure
- In practice, we are largely constrained to just dealing with the latter – reducing the size of the separated flow region
- There are no hard and fast rules to guide us on changing separation
- One thing we try to avoid is having hard edges in the wake of a body, as these will almost certainly define the limits of a separated flow region
- A second thing we try to avoid is having shapes that bend away from the freestream direction too rapidly. The diffusers we studied last topic were a good example – you want to keep diffuser angles to less than about 10 degrees

- We have seen earlier that turbulent boundary layers are more resistant to separation than laminar boundary layers. For this reason, with bluff body flow, it is often desirable to transition
- For example, golf balls have their dimples because the dimples promote transition to a turbulent boundary layer, which otherwise would not occur until a much higher Reynolds number
- The turbulent boundary layer can better withstand the adverse pressure gradient on the back half of a sphere in a flow, and thus the size of the separated flow region is reduced:

Figure 55 of van Dyke

Figure 57 of van Dyke

- Owing to the complexity of predicting when separation will occur, experimentation is the only way to know we have been successful in reducing pressure drag

- The experiments might look directly at the drag, or might visualize separation, as in the photos above

X. RELATED PROCEEDINGS APPENDIX

None.